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ABSTRACT

The research related to laboratory work in science instruction is reviewed in this position paper. The history of the laboratory is outlined from its roots in the nineteenth century, and the goals of the laboratory are enumerated from a review of the literature. Research findings are critically analyzed regarding the effectiveness of laboratory instruction and suggestions are made for overcoming the limitations observed in the studies to date. Specific areas identified as having high potential relevance for research on teaching and learning in the laboratory are reviewed, and suggestions are synthesized for the clarification of the role of the laboratory in science education. (GS)

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THE ROLE OF THE LABORATORY IN SCIENCE TEACHING:

RESEARCH IMPLICATIONS

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Position paper for a symposium organized by the authors at the National Association for Research in Science Teaching, Boston, April, 1980.

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FORWARD

This position paper has been prepared as an organizer for a symposium on Research on the Laboratory in Science Teaching to be presented at the convention of the National Association for Research in Science Teaching on April 12, 1980 at Boston, Massachusetts. Participants in the symposium are:

Introduction: V. Lunetta, The University of Iowa

The Practical Mode: P. Tamir, The Hebrew University, Jerusalem

Intellectual Development: R. Raven, SUNY at Buffalo

Affective Domain: A. Hofstein, The Weizmann Institute, Rehovot

Teacher-Student-Curriculum Interactions: J. Shymansky, J. Penick, The University of Iowa

Synthesis and Future Research: W. Welch, The Univeristy of Minnesota

The authors wish to thank all of the symposium contributors for their participation and for their helpful comments. Helpful comments were also received from Professor H. Walberg, The University of Illinois at Chicago Circle, on the implications of Learning Environments. Professor Pinchas Tamir reviewed the entire position paper and made extensive comments that were especially helpful.

Introduction

In 1970 the Commission of Professional Standards and Practices of the National Science Teachers Association thought that the case for school science laboratories too obvious to need much argument (Ramsey and Howe, 1969). They wrote: "That the experience possible for students in the laboratory situation should be an integral part of any science course has come to have a wide acceptance in science teaching. What the best kinds of experiences are, however, and how these may be blended with more conventional classwork, has not been objectively evaluated to the extent that clear direction based on research is available for teachers." Less than ten years later, some educators and the role of laboratory work, and the case for the laboratory in science instruction is not as self-evident as it once seemed (Bates, 1978). Yet, the laboratory has long been a distinctive feature of science education. Thus, the primary goals of this paper are to review the research studies that have been conducted thus far and to suggest further research that may be needed. More specific objectives are:

1. To briefly review the history and goals of the laboratory in science teaching;
2. To review and critically analyze research findings regarding the effectiveness of laboratory instruction;
3. To suggest methods for overcoming the limitations observed in the studies to date;
4. To suggest specific dimensions of high potential relevance for research on teaching and learning in the laboratory;

5. To provide a synthesis of suggestions for researchers working to clarify the role of the laboratory in science education.

For the purpose of this paper, laboratory activities are defined: as contrived learning experiences in which students interact with materials to observe phenomena in a laboratory classroom within a school. The contrived experiences may have different levels of structure specified by the teacher or laboratory handbook, and they may include phases of planning and design, analysis and interpretation and application as well as the central performance phase. Laboratory activities are normally performed by students individually or in small groups and our definition does not include large-group demonstrations. Specific characteristics of laboratory work that normally set it apart from verbal learning are the manipulation of physical objects, the gathering of information in a naturalistic setting, and the observation of properties and relationships by individual learners.

tical work in the laboratory with other methods of practical work over the past decades. For example, Coulter (1966) compared inductive laboratory experiments with inductive demonstrations in high school biology. Yager, et al., (1969) compared three groups, namely, "laboratory group", "demonstration group", and a "discussion group" in biology. Lunetta (1974) compared a control group to a computer-simulation group in physics, and Ben-Zvi, et al., (1976a) compared a laboratory group to a group viewing filmed experiments in chemistry. Most of these research studies have shown no significant differences between the instructional methods in student achievement, attitude, critical thinking, and in knowledge of the processes of science as measured by standard paper-and-

pencil tests. Research findings reported by Yager, et al., (1969) showed that a laboratory approach provided no measurable advantage over other modes of instruction except for the development of laboratory skills. Since many studies comparing the effects of laboratory learning with more conventional forms of instruction have resulted in non-significant differences, some science educators (Yager, et al., 1969; Bates, 1978; and Welch, 1979) have seriously questioned the need and effectiveness of laboratory work. On the other hand, serious deficiencies in the studies that have been conducted are often apparent when original reports are scrutinized. Furthermore, Stephens (1967) in a review of educational research, has written that 'instructional techniques' in general, seem to hinder learning as often as they aid it. There is reason to surmise that as of yet there is insufficient data to make sweeping generalizations on the optimal role of the laboratory in science teaching.

Science laboratory requirements are currently of special concern because of the expense of equipment and materials, administrative problems, and the time they consume in busy course schedules. Yet, the effort and expense involved in laboratory teaching may be justified if it can be shown that such teaching is uniquely successful in achieving important educational objectives. Bates (1978) concluded his review of the research literature with the following summary:

> "Teachers who believe that the laboratory accomplishes something special for their students would do well to consider carefully what those outcomes might be, and then find ways to measure them. If it is nothing else, this paper is an invitation to systematic inquiry, for the answer has not been conclusively found: What does the laboratory accomplish that could not be accomplished as well by less expensive and less time-consuming alternatives?"

Assessing the nature and goals of science teaching is especially important now since "there has been increasing dissatisfaction with present outcomes of education in the sciences and growing uncertainty about usefulness of science as a vehicle to assist people in making decisions on issues confronting contemporary society" (Yager, 1979). While the National Science Foundation is sponsoring several research projects (e.g., Project Synthesis) to explore new horizons in science education, it is also the time to examine more carefully the role of the laboratory in school science instruction.

We are already facing a trend in which there is a retreat from student-centered science activities resulting in a decline of time and experiences in the science laboratory (Gardner, 1979). This is a worrisome trend for many science educators who have generally considered the science laboratory to be an important or even central instructional medium. One of the reasons for this trend may well be the failure of existing research studies to support the value of laboratory work as a medium for effective science learning.

Brief History and Goals*

The history of laboratory work as an integral part of school science learning has roots running into the nineteenth century. The laboratory in the science classroom has long been used to involve students in concrete experiences with objects and concepts. In 1892 Griffin wrote (cited by Rosen, 1954): "The laboratory has won its place in

* Certain parts of this section are based on Tamir, P.: "The Role of the laboratory in science teaching", Technical Report No.10, Science Education Center, The University of Iowa, Iowa City, Iowa, 1976.

school; its introduction has proved successful. It is designed to revolutionize education. Pupils will go out from our laboratories able to see and do." In the years following 1910, the progressive education movement had a major impact upon the nature of science teaching in general and on the role of laboratory work in particular. John Dewey, leader of the progressive education movement, advocated an investigative approach and "learning by doing." During this period textbooks and laboratory manuals began to acquire a more applied, utilitarian orientation. Nevertheless, while the progressive education movement was gaining momentum, debate about the proper role of laboratory work was also developing. The arguments raised against extensive student laboratory activities included the fact that laboratory activities had not resolved many important problems of science teaching. These arguments included the following assumptions:

1) Few teachers in secondary schools are competent to use the laboratory effectively;
2) Too much emphasis on laboratory activity leads to a narrow conception of science;
3) Too many experiments are trivial;
4) Laboratory work in schools is often remote and unrelated to the capabilities and needs of the children.

While some criticized laboratory work, however, others claimed that laboratory experiences were indispensible (Craig, 1927, and report of Science Masters Association, 1953). In the period following World War I, laboratory activities came to be used largely for confirming and illustrating information learned from the teacher or the textbook.

The "new" science curricula of the 1960's resulted in several departures from tradition in the role of laboratory work. In "the new curricula which stress the processes of science and emphasize the development of higher cognitive skills, the laboratory has acquired a central role, not just as a place for demonstration and confirmation but rather as the core of the science learning process" (Shulman and Tamir, 1973). Contemporary science educators (e.g., Lunetta and Tamir, 1978; Hurd, 1969; and Schwab, 1962) have expressed the view that the major uniqueness of the laboratory lies in providing students with opportunities to engage in processes of investigation and inquiry. According to Ausubel (1968) the laboratory . . . "gives the students appreciation of the spirit and method of science, it promotes problem-solving, analytic and generalization ability. It provides students with some understanding of the nature of science."

A review of the literature revealed the following goals for laboratory instruction in science education:

1. To arouse and maintain interest, attitude, and curiosity in science;
2. To develop creative thinking and problem-solving ability;
3. To promote aspects of scientific thinking and the scientific method;
4. To develop conceptual understanding;
5. To develop practical abilities.

Anderson (1976) summarized the goals of laboratory work in the following four main areas:

1. To foster knowledge of the human enterprise of science so as to enhance student intellectual and aesthetic understanding;

2. To foster science inquiry skills that can transfer to other spheres of problem-solving;
3. To help the student appreciate and in part emulate the role of the scientist;
4. To help the student grow both in appreciation of the orderliness of scientific knowledge and also in understanding the tentative nature of scientific theories and models.

A Critical Analysis of Past Research Studies

Standardized instruments which were not designed specifically to measure outcomes of laboratory work have often been used to assess learning outcomes. These instruments should not be expected to discriminate between various laboratory instructional treatments, or to measure some of the important effects of laboratory learning. "Because he (the researcher) was so very certain that what he was about to do would drastically affect student learning, he did not bother to carefully choose his criteria to represent accurately what he expected to happen" (Welch, 1971). Researchers in science education have often been more concerned with the nature of treatments than with the validity of the instrumentation used to measure outcomes of their studies. Sufficient time has not been invested in the design and preparation of valid and reliable instruments for many of the variables purportedly examined in studies on the effectiveness of laboratory instruction.

One of the many examples of inadequate instrumentation is the Watson-Glazer Critical Thinking Appraisal (W.G.C.T.A., 1961) which has little or nothing to do with science teaching in general nor with laboratory work in particular. The Watson-Glazer Critical Thinking Appraisal was

used extensively as a measure of students' critical thinking ability. This instrument was constructed and validated for use in the social sciences and concerns itself with social and historical phenomena. While one can argue that "transfer of learning" is an important outcome of instruction, the differences between science laboratory experiences and historical and social events is very large.

The extensive use of T.O.U.S. (Test of Understanding Science, Cooley and Klopfer, 1961) provides another example of inadequate instrumentation. This test measures students' 1) understanding of the scientific enterprise, 2) understanding concerning scientists and 3) understanding of the method and aims of science. Research studies (e.g., Yager, et al., 1969) failed to show any growth of student understanding of the scientific enterprise as a result of laboratory-centered science curricula. Since this test reflects a very narrow conception of laboratory inquiry, there is good reason to question whether or not it is an appropriate test to measure outcomes of laboratory learning.

Welch (1971) has written that in thirty research reports concerning instructional procedures (including laboratory instruction) there has been a lack of connection between the instructional procedure and the test chosen to measure the effect. Ramsey and Howe (1969) pointed out that inquiry methods designed to have students working with the processes of science are likely to produce different outcomes than conventional procedures. More sensitive evaluation instruments need to be developed that will provide information about student growth and ability to develop inquiry and other laboratory-related skills (Lunetta and Tamir, 1978).

Research studies generally have narrowed the scope of laboratory instruction and the conclusions of each may apply only to a narrow range

of teaching techniques, teachers, or student characteristics. Furthermore, student samples have also been of limited diversity, and most of the research studies have not examined effects on different subsets of the population (e.g., less able or more able students); thus, only partial information has been obtained. They often have failed to report important variables descriptive of student abilities and aptitudes, and they have generally failed to note the amount and kind of prior lab experience. Most students involved in the studies have almost certainly had some prior laboratory experiences providing an additional confounding variable.

The studies reported in the literature frequently have embodied poor research design, inappropriate statistical treatment (Cunningham, 1946), and a comparatively small group size (Bradley, 1969). Not enough attention has been given to control over extraneous factors such as instruction outside the laboratory while the research study was being conducted, and these may well have been of sufficient consequence to provide new and substantial sources of variance. Incomplete reporting of experimental treatments (Belanger, 1971) has been another common and complicating factor.

Most of the research studies failed to look at teacher behavior, classroom learning environment and variables identifying teacher-student interaction. Most of the research studies have failed to assess and report what is really happening in the classroom and how the teacher translates the curriculum into action (Connelly, 1979; and Silberstein, 1979). An experiment can be open-ended and inductive when taught by one teacher and didactic and deductive when used by another teacher. There is a need for obtaining more objective information about the interactions taking place between teachers, curriculum resources, and students and about teacher

and student behaviors during a laboratory-based learning sequence. Eggelston, et al., (1976) found that teaching style tends to be consistent no matter what form of activity takes place. Didactic teachers teach practical work authoritatively while more inquiry-oriented teachers teach investigative methods of learning.

An important attempt to develop a systematic classroom interaction analysis in order to get more information on what actualiy happens in the laboratory was made by Penick, et al., (1976), who developed the Science Laboratory Interaction Category (SLIC-Student) and by Shymansky, et al., (1976) who developed the SLIC-Teacher. Using the two instruments one can obtain information about the kind of teaching and learning taking place in the science laboratory. Tamir (1977) used the classroom observation schedule developed by Smith (1971) to observe students conducting experiments in the biology laboratory. This instrument provides a record of teachers' and students' pre-lab, lab, and post-lab activities.

Barnes (1967) developed an instrument (paper-and-pencil) called Biology Laboratory Activity Checklist (BLAC). This instrument attempts to measure the nature and extent of laboratory instruction and activities in high school biology instruction as perceived by the students. The laboratory activities that were evaluated were: 1) prelaboratory activities, 2) laboratory activities, 3) post-laboratory activities, and 4) general student reaction to the laboratory. This practical technique enables one to find out the extent to which high school biology laboratory activities of teachers are in agreement with the activities advocated by the curriculum developers.

Herron (1971) building upon Schwab (1960), has described four levels of guidance for the science laboratory. These levels of guidance or open-

ness for laboratory investigation were defined in terms of: methods, problems, finding data, and relationships or interpretations. Depending upon the level of guidance, some of the information is given to students in the laboratory manual and other information must be discovered or observed in laboratory activity. Table 1 provides a summary of Herron's definitions of four levels of guidance using these components.

TABLE 1

Levels of Guidance in a Laboratory Exercise

LEVEL	PROBLEMS	METHODS	INTERPRETATIONS
0	Given	Given	Given
1	Given	Given	Open
2	Given	Open	Open
3	Open	Open	Open

With more information and research, careful analysis and selection of laboratory activities according to the pattern suggested by Herron, a teacher could match activities to student abilities, needs, and expectations, and to more precise teaching objectives.

One of the key components of learning in the laboratory is the students' laboratory manual. The laboratory manual plays a major role for most teachers and students in defining goals and procedures for laboratory activities. It also helps to focus observations and the development of inferences, explanations, and other activities in laboratory investigation (Lunetta and Tamir, 1978, 1979). Recognizing the need to examine the quality of written laboratory manuals, Fuhrman, et al., (1978) designed a task analysis inventory (LAI). This inventory was found to be a useful instrument in analyzing laboratory manuals. The task categories

include actual behaviors required to perform prescribed laboratory work and inquiry. Comprehensive research into the learning effectiveness of laboratory instructicn should also include a summary and analysis of the kind of laboratory manual that has been used. Studies could be undertaken to find out how published materials are actually used in the laboratory.

In a comprehensive review of the objectives of science laboratory work, Shulman and Tamir (1973) found that these are the same as objectives generally stated for science learning per se. Thus, it should come as no surprise when research studies do not report significant differences in learning among students receiving laboratory and non-laboratory instruction. Furthermore, most of these research studies have neglected to assess important and unique outcomes of laboratory work, namely, practical experiences (the "pracitcal mode", Tamir, 1972; and the "practical domain", Ben-Zvi, et al., 1977). Among these practical experiences are investigative, inquiry, manipulative, and observational skills that have a wide range of generalizable effects (Olson, 1973; Tamir, 1975).

Olson (1973) distinguishes between three modes of instruction: "direct experience", "modeling or observational" and "information transmitted" (through speech, film, etc.). The practical mode (Tamir, 1972) is the mode in which the student is provided with an opportunity for direct experiences in the laboratory. This "direct experience" mode involves both manual and intellectual abilities that are distinct from non-practical work (Kelly and Lister, 1969; Tamir, 1972; and Ben-Zvi, et al., 1977). Thus, if we are dealing with a unique mode of instruction then there is a need for a unique mode of assessment (Tamir, 1975). Practical skills should be measured by practical tests.

According to Olson (1973) research studies failed to show signfi-

cant advantage of one instructional mode over another since "these studies typically assess only the knowledge conveyed at the level at which these systems converge and overlook the skills developed--the point at which they diverge." Researchers in the future might also examine the role of the laboratory in science teaching in a more wholistic way as well as to consider outcomes of certain narrow instructional techniques. In addition to careful monitoring of the variables mentioned in this section, however, the examination of student learning and growth needs to be expanded to gather data in areas of high potential interest and relevance that have been ignored in many of the studies conducted thus far.

Research Areas With High Potential for Contemporary Study

Many of the reasons used to justify the importance of the laboratory in science teaching have been based upon the hunches and educated guesses of scientists and science educators. There is a special need at this time to examine these assumptions on the basis of carefully gathered research data.

Bates (1978), Dickinson and Sanders, (1979) and many others have claimed that there is a need for more specific evidence about how laboratory experiences help or hinder students' abilities in science education. There is also reason to surmise that the effects of laboratory learning upon some of the instructional goals reviewed earlier in this paper have not yet been thoroughly examined. Some of these goals provide bases for dimensions of research having especially high potential for contemporary study on the role of the laboratory that are reviewed in this section.

Attitude, Interest and Curiosity

Developing favorable attitudes toward science has often been listed

as one of the important goals of science teaching. Unfortunately, relatively little research has been directed at the affective goals of laboratory instruction, but it has usually been assumed that having a wide variety of instructional materials available including laboratory activities, audiovisual materials, field trips, etc. will enable teachers to vary classroom procedures in order to avoid monotonous activities and to arouse interest, curiosity, and attention. Smith, et al., (1968), Selmes, et al., (1969), Ben-Zvi, et al., (1976), and Hofstein, et al., (1976) found that students enjoy laboratory work (in certain grades) and that laboratory work generally results in positive and improved attitudes . . . However, there can also be too much of a good thing. Hofstein, et al, (1976) found chemistry students' attitude toward laboratory work to be comparatively high, although there is significant decline in attitude from 10th to the 12th grades. These findings lead to the conjecture that because of increasing age, experience, and sophistication, chemistry students in the 12th grade find laboratory work less stimulating than in previous grades. Yet, another explanation could be that different kinds of laboratory experiences would be more appealing to students at that age. It is also probable that from the 10th to the 12th grade it would be best to change the amount of guidance provided to the student in the laboratory. These hypotheses should be examined in the future.

In a research study conducted by Ben-Zvi, et al., (1976) students were asked to rate the relative effectiveness of instructional methods. Students reported that personal laboratory work was the most effective instructional method for promoting their interest when contrasted with teacher demonstrations, group discussions, filmed experiments, and lectures. Similar results were obtained by Bybee (1970) in comparing labor-

atory versus lecture demonstrations in an Earth Science course at the college level. In a study in chemistry, Charen (1967) found that open-ended laboratory experiments enhanced students' attitudes toward the learning of chemistry. Similar findings were obtained by Smith, et al., (1968) who found that students preferred laboratory work to other instructional techniques. Johnson, et al., (1974) compared three groups of sixth grade science students: a group who learned science from a textbook, a group who used both textbook and lab materials, and an activity-centered group that worked primarily with materials. They found that students who interacted with concrete materials developed significantly more positive attitudes than those who studied from books alone.

Lawrenz (1975) reported a decline in attitude toward, and interest in science as a result of studying science courses. However, Welch (1979) has hypothesized that laboratory work could contribute to a positive attitude in those instances in which the student is involved in more interesting, problem-solving-type laboratory activities.

To help children develop attitudes which foster the development of scientific inquiry is a commonly state goal for science teaching. Aiken and Aiken (1969) called these "the more cognitive scientific attitudes" that include traits such as intellectual curiosity. Brown (1976) described the situation well when she wrote that if one of the goals of science education is to teach students to think as scientists, then we would expect emphasis on the development of attitudes that good scientists are expected to display. It is reasonable to assume that laboratory activities will affect the development of such attitudes and this kind of hypothesis should certainly be examined.

Sears and Hilgard (1964) claimed that curiosity is one of the neglected

motives which is important in school learning and that in the future more attention should be paid to it. The extent to which science teaching is successful in developing curiosity in children is not clearly known but one can also hypothesize that proper kinds of laboratory work could help in developing it for certain students. Curiosity has been identified as one of the important affective components of the inquiry method (Bingman, 1969). A scientific curiosity inventory was developed by Campbell (1972) and used by Tamir (1978) and Hofstein, et al., (1980). This inventory was limited to the three levels of the taxonomy (receiving, responding, and valuing) in the affective domain (Krathwohl, Bloom and Masia, 1964), and it attempted to measure how far the student would be willing to go to satisfy his curiosity. Peterson (1977) has also conducted research on childrens' curiosity. Her study was based on observing childrens' behavior in a "science-enriched environment" including looking, smelling, testing, listening, touching, etc. Peterson's findings suggest that young childrens' styles of expressing curiosity related to their senses are stabilized by elementary school age so teachers must be sensitive to "individual differences". She discriminates between those who express curiosity through sensory input, exploring objects and materials, and those who prefer to ask questions or explore verbal materials. Peterson's conclusions that different students exhibit different patterns of curiosity is important for the future design of research in laboratory instruction.

In summary, if one agrees that "we are entering an era when we will be asked to acknowledge the imporance of affect, imagination, intuition and attitude as outcomes of science instruction that are at least as important as their cognitive counterparts (Shulman and Tamir, 1973), then, the

affective outcome of laboratory instruction can certainly not be overlooked in research study as it generally has been up to this time.

Locus of Control

The study of locus of control is another promising area for research on the effect of laboratory instruction. This measure of cognitive style is an attempt to classify a person's beliefs about his ability to control his own destiny. Does the person believe that destiny is self-determined or controlled by outside forces? Research has suggested that locus of control is rooted in school, family, and cultural experiences and that it is one of the variables that has an important effect on student learning and behavior. While there is much we do not yet know about locus of control and the laboratory, there is reason to hypothesize that a student's locus of control can be modified through the right kinds of laboratory experiences and that these changes may have positive, long-term effects upon behavior and cognitive learning in science.

The Cognitive Domain

Research studies on the laboratory normally have attempted to measure learning outcomes in the cognitive domain. While these studies have often examined growth in understanding of concepts of particular science disciplines, they have generally failed to examine growth in other cognitive variables such as creative thinking, problem-solving, scientific thinking, and intellectual development. These important cognitive variables are probably interrelated and have special potential for research study on the effects of laboratory learning.

Creative Thinking and Problem-Solving. In the 1960's there was a call for a "new" kind of science teaching. Articles and books appeared arguing that the methods used in the past no longer met the challenge

of the new age (Getzels, 1963). The new change was to emphasize generalization, discovery, and inquiry. An elementary resource book cited by Getzels (1963) included in its statement of objectives: "To maintain and expand childrens' interest and curiosity through use of exploration in problem-solving activity as the basis of the learning process." According to Romey (1970), creativity is the ability to combine ideas, things, techniques or approaches in a new way. The creative student is one who is able to ask more original questions concerning a scientific phenomenon (Lehman, 1972). Certain kinds of open-ended laboratory activities in which the student is involved in a problem-solving situation might provide the best opportunitites for students' creative thinking to develop. In situations when the problem is given but no standard method for solving it is known to the problem solver or when a problem exists but it remains to be identified or discovered, there is a need to discover and to go beyond the information given. These are situations in which students can be encouraged to practice processes considered to be creative and original.

The laboratory is an important place to introduce students to problem-solving through experimental methods (Ramsey and Howe, 1969) as well as to increase their comprehension. However, very few studies in the literature describe attempts to measure creativity and problem-solving and laboratory activities are seldom used in ways that would foster students' ability to solve scientific problems. Penick (1976) reports findings that suggest a growth in creativity in fifth grade students as a result of science laboratory experiences. Hill (1976) found that college student creativity using the Minnesota Test of Creative Thinking was improved through involvement in chemistry laboratory activities.

Reif and Larkin (1979) conducted a systematic study of skills for solving problems in basic physics. They have formulated a theoretical model which was incorporated into experimental instruction and they hope to extend their work and develop instructional procedures that will apply their findings.

Scientific Thinking. Many educators have claimed that the laboratory is one of the important vehicles for teaching understanding of the processes of scientific thinking. According to Lucas (1971), students can understand how scientists work and think and also how to acquire new knowledge themselves by personally practicing the use of inquiry. Ramsey and Howe (1969) have pointed out, however, that inquiry methods and methods designed to involve students with the processes of science are likely to produce different learning outcomes than are conventional instructional procedures. Yet, sensitive evaluation instruments must be developed and used that will provide information on students' growth and competency in scientific thinking.

Burmester (1953) designed a paper-and-pencil test to measure some of the aspects of students' ability to think scientifically. Under the heading scientific thinking she included the following:

1. ability to recognize problems;
2. ability to understand experimental methods;
3. ability to organize and interpret data;
4. ability to understand the relation of facts to the solution of problems;

5. ability to plan experiments to test hypotheses;

6. ability to make generalizations and assumptions.

It has been hypothesized that inquiry-based laboratory activities in which the student examines an interesting problem could enhance the attainment of many of these abilities. A research study conducted by Kaplan (1967) showed student pretest-posttest gains using Burmester's Inventory resulting, at least in part, from the use of a laboratory manual designed to teach aspects of scientific thinking.

A very careful study reported by Reif and St. John (1979) showed that students in a specifically designed college level physics laboratory course developed higher level skills more successfully than did students in a conventional physics laboratory course. These studies examined the students' ability to:

> "(1) apply the underlying theory of an experiment to solve a similar problem involving a different physical situation; or
>
> (2) modify the experiment to find a different quantity, or to find the same quantity by using different methods; or
>
> (3) predict the effect of an error in an experimental procedure or measurement" (p. 954).

The students in this specially designed lab course used instructional materials that presented "information in a carefully organized way and incorporated specific features stimulating students to think independently" (p. 952). Generally, in the literature, however, there is very little evidence that such important outcomes of laboratory instruction have been evaluated in careful and extended research study. Until instrumentation is developed, and more extensive data gathered and evaluated, decisions will continue to be based upon assumptions and speculation and not entirely based upon factual evidence. There is real need for careful

research here.

Students' Intellectual Development. Instructional strategies in science, have, over the past decade, been influenced by the developmental theory of Jean Piaget. In general, curriculum revision and design have been directed toward the incorporation of concrete materials in laboratory settings requiring active involvement on the part of the students (e.g., Lawson and Wollman, 1976).

Renner and Lawson (1973) and Karplus (1977) have proposed a learning cycle to promote science learning and students' intellectual development that consists of:

1. exploration: the student manipulates concrete materials and explores questions and relationships of interest;

2. concept introduction (invention): teachers introduce terminology and structures relevant to the materials that have been explored;

3. concept application (discovery): the student investigates further questions and applies the new concept in related but novel situations.

Fix and Renner (1979) have used Jean Piaget's (1970) theory and Karplus' (1977) learning cycle as a model for teaching certain concepts in high school chemistry in Oklahoma. In that work it was assumed that the building of mental structures occurs when learners repeatedly interact with what is to be learned (assimilation), gather data about those relationships, and invent explanations for those concepts and relationships (accomodation). Assimilation in this context resulted from interaction with materials of chemistry through first hand experiences. They also showed that as a result of this laboratory-centered chemistry curriculum the enrollment in chemistry was increased and student scores on ACT tests over ten years were significantly improved. The work done by Fix and

Renner was an important breakthrough in science teaching since the program made a well-developed attempt to match curricula to students' intellectual development. On the other hand, it would be unwise to generalize broadly on the basis of the data reported in this study without extending the study to other samples. Furthermore, it is difficult to discern from the published account of this study how much of the reported improvement in achievement is actually due to work with materials in the laboratory and how much is due to other variables that are unrelated to laboratory investigation.

It is quite clear that many interpreters of Piaget infer that work with concrete objects is an essential part of the development of logical thought, particularly prior to the time that an individual reaches the developmental stage of formal operation thought. At this time, however, to the external reader of Piagetian research, it is not entirely clear whether this inference is data-based or simply an assumption of the Piagetian paradigm. Certainly, an analysis of this question is needed at this time and has the potential to shed light on the need for school laboratory experience. If the analysis supports the need for laboratory experiences, can contact with symbolic representations be as good as contact with objects? -- is there a minimum level of such experiences that is essential? A second question of similarly great importance is the amount of structure that is optimal in facilitating intellectual development for individual students. Interpreters of Piaget within the paradigm have mixed opinions on this question at the present time (Doyle and Lunetta, 1978). Yet, "Continuing research on the role of science teaching in nurturing intellectual development may, in the relatively near future, provide . . . new science teaching curricula in which pro-

perly designed laboratory activities will have a central role" (Bates, 1978).

The Individual Learner. In summarizing the results of their study, Yager, et al., (1969) suggested matching laboratory experiences to student characteristics. "For certain students and certain teachers a verbal non-laboratory approach may be the best means of stimulating them to understand and appreicate science." Shulman and Tamir's (1973) reaction was "There is no doubt that before any far reaching conclusions can be generally attempted, replications of the study with different students . . . in different schools and age groups using different subject matter should be carried out." One teaching method may have dramatically divergent effects on different students.

The need to match the learning experiences to students' individual needs was also stressed by Ben-Zvi, et al., (1977) in Israel. It was found that students who chose to become non-science majors and who had studied chemistry for one year (in the 10th grade) scored significantly lower than did science majors on cognitive measures, but they scored similarly on measures of the "practical domain" (problem-solving, observation, manipulation skills). The study also suggested that if the "practical domain: were eliminated from Israeli chemistry class learning, non-science students would have left school with a negative attitude toward science in general and towards chemistry in particular.

Practical Skills and Abilities

Ramsey and Howe (1969) claimed that the area of psychomotor skills has been almost completely ignored by researchers in science education.

Grobman (1970) observed that in the "new" science teaching projects: "with few exceptions, evaluation of developmental projects has depended on written testing . . . there has been little testing which requires actual performance in a real situation, or in a simulated situation which approaches reality . . . to determine not whether the student can verbalize a correct response but whether he can perform an operation, e.g. a laboratory experiment or an analysis of a complex problem . . . This is an area where testing is difficult and expensive, yet since in the long run primary aims of laboratory projects generally involve doing something rather than writing about something, this is an area which should not be neglected in evaluation of criteria." Although some recent attempts have been made to incorporate practical examinations within evaluation projects (Kelly and Lister, 1969; Tamir, 1974; and Ben-Zvi, et al., 1975) "the research and the relation between the laboratory and other learning modes remains scarce" (Shulman and Tamir, 1973).

According to Kelly and Lister (1969) "Practical work involves abilities both manual and intellectual, which are in some measure, distinct from those used in non-practical work and thus, "the evidence points to the value of using profiles of different aspects of student performance in obtaining valid evaluation data" (Kelly, 1971).

Robinson (1969) found that a low correlation exists between laboratory-based practical examinations and written paper-and-pencil tests. For this reason and others, there is an urgent need for special instruments to evaluate the learning of laboratory skills. Practical test have been designed by Tamir and Glasman (1970) and by Ben-Zvi, et al., (1976) in Israel, by Eglen and Kempa (1974) and by Kelly and Lister (1969) in the United Kingdom and by Robinson (1969), Jeffrey (1967), and by Golman

(1975) in the United States.

Jeffrey (1967) suggested six areas associated with laboratory work:

1. Communication: identification of laboratory equipment and operations;
2. Observation: recording of observations and detecting errors in techniques;
3. Investigation: accurate recording of measurable properties of an unknown substance;
4. Reporting: maintenance of a suitable laboratory record;
5. Manipulation: skills in working with laboratory equipment;
6. Discipline: maintenance of an orderly laboratory and observation of safety procedures.

Jeffrey is among those who have stressed the need to design practical examinations in which the students will be involved in manipulating apparatus and materials. According to Kempa and Ward (1975) the overall process of practical work in science education has four major phases: 1) planning and design of an investigation in which the student predicts results, formulates hypotheses and designs procedures; 2) carrying out of the experiment, in which the student makes decisions about investigative techniques and manipulates materials and equipment; 3) observation of particular phenomena; 4) analysis, application and explanation in which the student processes data, discusses results, explores relationships and formulates new questions and problems. Tamir (1974) has designed an inquiry-oriented laboratory examination for Israeli biology students. The student is evaluated on the bases of the following criteria: manipulation, self-reliance, observation, experimental design, communica-

tion, and reasoning. Jeffrey (1967), Tamir (1974) and Kempa and Ward (1975) created what could serve as an organizer of objectives of laboratory work that could serve in the design of meaningful instruments to assess the outcomes of laboratory work.

It is reasonable to assert with Olson (1973) that "the laboratory provides conditions for the acquisition of both intellectual and motor skills--namely, an occasion for performance as well as feedback"; thus, the assessment of these skills should certainly not continue to be overlooked in both instruction and in research on the effects of laboratory learning.

Social Variables

In recent years conceptualization and assessment of the human environment has assumed considerable attention (Anderson, 1969; Anderson and Walberg, 1974; and Walberg, 1976). The interest in learning environments is reflected in large numbers of recent studies involving students' perception of the classroom learning environment. Studies involving classroom learning environment variables have shown that students' perceptions of classroom environment are good predictors of both cognitive, affective and behavioral measures of learning (Walberg, 1979; and Rentoul and Frazer, 1980).

The learning environment was defined by Anderson (1973) as "the interpersonal relationship among pupils, relationship between pupils and their teachers, relationship among pupils and both the subject matter studied and the method of learning and finally, pupil perception of the structural characteristics of the class." According to Walberg (1969) perception of learning environment is a measure that is sensitive to instructional and psychological treatments; measures of perception of

the learning environment can differentiate between classrooms using different instructional methods. Rentoul and Frazer (1980) using a modified version of the Learning Environemtnal Inventory (LEI) are now studying whether or not his instrument distinguishes between inquiry-based science classes and non-inquiry-based classes.

There is need for more intensive research that will assess how the time alloted for laboratory work and activities taking place in the laboratory affect classroom environment. It has been suggested that certain learning environment variables are affected by the kinds of laboratory work activities in which the students is involved. Support for this assumption is given by Egelston (1973) who found that different types of laboratory activities (inductive vs. deductive) displayed different learning environments as measured by the Learning Environmental Inventory (LEI) (Anderson, 1973) and by a preliminary study by Hofstein, et al., (1980).

Since creating a "healthy" learning environment is an important contemporary goal for many educators, it will be worthwhile to ascertain the effects of different modes of practical work (didactive vs. inductive; discovery vs. confirmation) on classroom learning environment. It will also be worthwhile to examine the effects of the amount of practical work on classroom learning environment.

Summary

The science laboratory is a unique mode of teaching and learning in science education. Yet, research on alternative ways of conducting and organizing the laboratory and on relations between the laboratory and other learning modes remains scarce (Ramsey and Howe, 1969; and Shulman and Tamir, 1973). In past years a number of studies have examined the

role of the laboratory in science education. However, at this time there is insufficient data from well-designed studies from which to make unequivocal statements on the role and effectiveness of laboratory work in science teaching. Research studies have often compared one method of laboratory work with other methods of laboratory work or with more conventional classroom teaching over relatively short periods of time. Most of these research studies have reported non-significant results. If differences have occurred in the growth of students involved in laboratory experiences when contrasted with more conventional instruction, the differences have generally been masked by confounding variables, by insensitive instrumentation, or by poor experimental design. Attention has seldom been given to the selection and the characteristics of the student sample or even to describing the nature of the laboratory instruction. Variables measured and controlled have often been only a subset of important dependent and independent variables.

Research must now be done on specific conditions, methods, and strategies of laboratory work and on their effect on learning outcomes. Research into the effectiveness of science laboratory experiences should use valid methods to monitor dependent and independent variables more carefully than have studies in the past. Important variables that ought to be monitored include:

1. teacher behavior;
2. student behavior;
3. content of laboratory manual and laboratory activities;
4. classroom environment;
5. student characteristics and abilities;

6. student attitudes toward a variety of relevant issues;
7. student manipulative abilities;
8. student conceptual understanding;
9. student inquiry skills;
10. laboratory management variables:
    a. time alloted to laboratory work;
    b. availability of laboratory space and resources;
    c. method of grouping students.

Researchers need to be especially careful in the selection, control, and documentation of activities prior to and during the research study.

Research should also look carefully at promising variables neglected in past studies. These variables include the development of problem-solving and logical skills, and positive attitudes toward science and toward the student's perception of his ability to understand and to change his environment. The data available does provide tentative evidence that these skills are enhanced through laboratory experiences for many students.

Researchers have not comprehensively examined the effects of laboratory instruction upon student learning and growth in contrast with other modes of instruction, and there is insufficient data to convincingly confirm or reject many of the hypotheses that have been stated about the importance and the effects of laboratory teaching. The research has failed to show simplistic relationships between experiences in the laboratory and student learning; the variables and their interrelationships are complex. This revelation should not be especially surprising considering the complexity of human learning; much more information and study are needed to clarify the relationships that do exist. Certainly,

it would be unreasonable to assert that the laboratory is an effective and efficient teaching medium for achieving all goals in science education. On the other hand, sufficient data do exist to indicate that laboratory instruction plays an important part in the achievement of some of these goals.

Researchers need to examine the goals of science teaching and learning with care to identify optimal activities and experiences from all modes of instruction that will best facilitate these goals. It is reasonable to assume that laboratory teaching is one of the more important modes of instruction for the science teacher. Certainly, laboratory teaching learning learning cannot be rejected as an important mode of instruction on the basis of the studies conducted to date. Laboratory teaching may well be an efficient mode of instruction depending on the development of the individual learner and upon the goals of instruction.

Surveys of the literature have shown that objectives defined for laboratory work have been almost synonymous with those defined for science learning in general. Thus, there is a need to redefine the special goals of laboratory work to capitalize upon the uniqueness of this mode of instruction for certain students and learning outcomes.

While variables are interrelated and complex, there is real need to vigorously pursue research on learning in the laboratory. With more precise information on these important questions, teaching models can be designed to incorporate information about goals, the nature of science, and the way people learn that will enable science teachers to become more effective in facilitating student learning and development.

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